Putting it all together: synthesis of multiple long-term monitoring programs to inform effective water quality offsets.

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Key Points

- Effective design and use of nutrient offsets requires detailed knowledge of source, transport and fate of nutrients.
- By synthesising multiple datasets from multiple sources, we provide insight to total nitrogen (TN) dynamics in an urban estuary not possible with any single dataset alone.
- TN dynamics during both low and flood flows means that catchment-based offset actions may not effectively improve water quality impacts of point sources in the estuary.
- Nutrient offsets must impact the same location and time as point-source discharges to improve water quality.

Abstract

The Queensland Point Source Water Quality Offset Policy (2019) provides an alternative mechanism for managing the water quality impacts of point-source nutrient discharge. The policy allows for the load of nutrients emitted from a point source to be offset by reducing nutrient inputs at another location. Streambank erosion control has been the primary method of offset applied under the policy.

The Brisbane River estuary receives the greatest load of point-source nutrients in Queensland and streambank erosion in the catchment is a known threat. This situation provides both the demand and potential supply of nutrient offset actions. Using 21 years of comprehensive monitoring of ambient nutrient concentrations, catchment flows, and point-sources discharge, we assessed the relative influences of point and diffuse sources of N in the Brisbane River estuary. This informs how effective catchment-based offset actions may be at reducing nitrogen in estuary waters.

We found that under low flow conditions, diffuse sources of N from the catchment had little influence on the estuary, however, point source loads could be used to model the ambient concentrations. During flood flows, diffuse N dominated load, was transported through the estuary without processing, and delivered to coastal waters. Low flow conditions quickly re-established following floods.

Nutrient offset methods of diffuse N reduction, such as streambank erosion control in the catchment, do not effectively mitigate point-source impacts downstream in estuaries. To effectively mitigate water quality impacts of point-sources, nutrient offset actions must be effective for the same timing and location of impact as point-source discharge.

Keywords

Nutrient offsets; Total Nitrogen; point-source

Introduction

Discharge of point-source nutrients from wastewater treatment plants and industrial sources can be a significant impact to the quality of receiving waters, particularly in areas of high population density (Tuholske et al. 2021). Investments to improve treatment processes and technology can reduce nutrient burden on receiving waters, however there is a point at which upgrades become prohibitively expensive for diminishing improvements to water quality outcomes (Lu et al. 2023). Nutrient offsets provide a potential alternative to meet wastewater discharge regulations and further reduce environmental impacts of point sources (DES 2019; Lu et al. 2023). The use of nutrient offsets in waterway management is a growing field and requires rigorous scientific support to achieve improvements in water quality outcomes.

In Queensland nutrient offsets are managed under the Point Source Water Quality Offsets Policy 2019 (DES 2019). The intent of this policy is to provide alternative investment options to meet wastewater discharge requirements that provide an improvement in water quality of the receiving environment. For a nutrient offset to be effective at achieving the intent of the policy and provide a water quality improvement, the offset needs to be effective in the same receiving waters, at the same time as point source impacts.

The Brisbane River estuary is an anthropogenically impacted waterway in southeast Queensland. It flows through an urbanised region, but with a freshwater catchment largely disturbed with agricultural land uses. The estuary directly receives continuous point-source loads of nutrients from 16 regulated facilities, and large catchment-derived loads of sediment and nutrients during sporadic high-flow events (Coates-Marnane et al. 2016). Significant investment was made to upgrade many wastewater treatment plants to improve nitrogen (N) and phosphorus treatment capacity between 2000 to 2008, which resulted in measurable reductions in nitrogen and phosphorus concentrations in the estuary (Saeck et al. 2019). However, continuing population growth has seen nutrients in the estuary increase again over time. As a consequence of this regional context, there is both a high demand for nutrient offsets as a management option for point-source nutrients, and the potential for offsets to be supplied by rehabilitation actions in the upper catchments. Nutrient offsets are likely to be a significant factor in management of the river in the future.

For nutrient offsets to be applied effectively over larger distances and areas, greater understanding of the source, transport and fate of nutrients is required to design effective offset actions. Greater distance between the offset action and location of a point source discharge reduces the certainty that the offset action will effectively mitigate the water quality impacts of the point-source discharge. This is also true where offset actions are not impacting water quality at the same time as point-source discharges occur.

In this study we aimed to use existing water quality monitoring program data, and regulatory reported point-source discharge data to understand the source and fate of nitrogen in the Brisbane River estuary. This understanding will better inform the application and design of nutrient offset actions in managing nutrients and water quality in this estuary.

A detailed paper of this study was recently published in Science of the Total Environment (Newham et al. 2024). In this paper we are focusing on how we combined data from separate monitoring programs, reporting formats and sources, to gain an understanding of total nitrogen (TN) in the estuary that would not have been possible without synthesising these disparate data sources.

Data sources

The Brisbane River Estuary (Figure 1) is one of the most highly monitored and sampled waterways in Queensland. Data sources include government, industries and the local NRM body. Monitoring of water quality occurs for regulatory and public reporting purposes. These datasets have not previously been integrated and are housed across different organisations, departments and in different formats.

Bathymetry data for the Brisbane River estuary was provided by Healthy Land and Water (HLW; https://hlw.org.au) from the Brisbane-Bremer Receiving Water Quality Model. This bathymetry data was last updated in 2019.

Ambient water quality data was provided from the estuarine Ecosystem Health Monitoring Program (EHMP). This program is a joint effort between HLW and the Department of Environment, Science and Innovation (DESI). The program samples 15 sites, 8 times each year (monthly up to 2014) in the estuary between 1 and 81 km from the river mouth. Samples are collected for nutrients and chlorophyll-a, and a range of in-situ measurements for physical-chemical properties are recorded.

Catchment inflows are measured at gauge stations that capture 90 % of the total catchment area of the estuary. Flow gauges and data are maintained by the Department of Regional Development, Manufacturing and Water (DRDMW; https://water-monitoring.information.qld.gov.au/). At gauges on the Bremer River and Warrill Creek the South East Queensland Catchment Loads Monitoring Program (SEQ CLMP) has collected flow event and monthly ambient samples of nutrients and sediment since 2007 for the purposes of calculating sediment and nutrient loads from these catchments. At Mount Crosby Weir on the Brisbane River, daily discharge data and nutrient samples were made available by Seqwater (https://seqwater.com.au).

Point-source discharge volume and concentration data from regulated facilities are reported to Qld Government through the Water Tracking and Electronic Reporting System (WaTERS), maintained by DESI. The Brisbane River estuary received point-source loads of nitrogen from up to 16 regulated facilities between 2001 and 2022. Many of the facilities report discharge volumes for each day, and concentration results from weekly up to monthly sampling frequency, depending on license conditions.

Data Analysis and Results

Estuary characteristics

The estuary volume was calculated using bathymetric data provided by HLW. The volume for each 1 km section of the estuary was calculated up to 81 km upstream of the river mouth. Total estuary volume was calculated as 165,610 ML.

For this study, we separated the estuary into two reaches. The lower estuary which extends from the river mouth to 33 km upstream, and the mid-upper estuary which extends from 33 to 81 km upstream of the river mouth (Figure 1). Overall TN dynamics were found to differ between these two reaches.

Point-source discharge of Total Nitrogen

The discharge of TN to the estuary was calculated from point-source discharge volume and concentration data. Daily volume of discharge along with the concentration provided daily load of TN as a mass. Concentration data, generally sampled weekly, were applied to each day of discharge until a new value was recorded.

The discharge of point-source TN to the estuary has not been consistent over time. Significant investments to upgrade wastewater treatment plants between 2000 and 2008 greatly reduced the load of TN discharged to the estuary (Figure 2; Saeck et al. 2019). Since 2008 the estuary has received an average TN load of 545 ± 18 year^{-1}. However, the load has been increasing at an average rate of 12 t year^{-1}.

Total Nitrogen store and concentration

The store of TN in the estuary was estimated for each EHMP sampling occasion. The concentration of TN was linearly interpolated between EHMP sites to provide a concentration for each 1 km section of the estuary. With known volumes, the store of TN for each section and the whole estuary could then be calculated. Between 2008 and 2022 the average store of TN in the estuary was 115 ± 3 t, and before WWTP upgrades the average store was 200 ± 10 t.

In the lower estuary, under low flow conditions (flow <0.5% of estuary volume), TN concentration can largely be explained by dilution processes (Figure 3). For each EHMP sampling occasion, expected concentrations of TN were calculated using upstream concentration, marine water concentration, and salinity as a conservative tracer. Dilution was found to explain 98 % of variation in the observed TN concentrations. Only a small amount of removal was found to occur. There was an average of 2 t less TN observed than expected by dilution processes in the lower estuary, from an average store of 67 t.

In the upper estuary, at low flows the observed TN store (from EHMP data) was found to track point-source discharge loads, with a time lag, when plotted. From this observation we set out to attempt to model the TN store in the mid-upper estuary using the daily load of TN from point-sources. We found that TN store could effectively be modelled using a constant background store, the daily point-source loads, and a decay rate of point-source TN (Figure 4). Using a training dataset from the low flow period of 2004 through 2007, the model was maximised for goodness-of-fit (GOF) to determine the unknown parameters of background store and decay rate of point-source TN. The modelling determined a background store of 39.3 t of TN in the mid-upper estuary reach, and a decay rate of point-source TN of 2.1 % day^{-1}, with a GOF of 91 %. For 2018 to 2022, we found the average store of TN in the mid-upper estuary to be 64.5 ± 0.6 t, equivalent to an average concentration of 1.15 mg L^{-1}. The store due to point-sources was almost 40 % of the total at 25.2 ± 0.6 t. This modelling exercise, using data from ambient monitoring, bathymetry volume, and point-source discharge, shows that the point-sources have a large influence on overall store of TN in the estuary.

Flood event TN dynamics

The estuarine EHMP conducted sample surveys of the estuary before, during and after a significant flood event between February to March 2022. The results of these surveys provide insights into the TN transported during significant flood events. The flood event occurred between 25 February and 16 March 2022, with the flood peak occurring on 28 February. Over the flood event, total discharge volume was equivalent to 21 times the whole estuary volume. At the time of each sampling occasion before, during and after the flood, the flow to the estuary was equivalent to 0.1 %, 42 %, and 2 % of the estuary volume per day respectively. The sample taken during the flood event was collected 8 days following the flood peak, which had a flow equivalent to 300 % of the estuary volume per day.

Figure 5 shows the concentration of TN along the estuary for each of these sample times. Before and after the flood event there is a peak of TN concentration in the mid estuary >1 mg/L, with lower concentrations both upstream and downstream of this point. During the flood event, the concentration of TN was constant throughout the estuary at about 0.83 mg/L. This shows that nitrogen is not being removed from the water column during the flood event and is being transported directly to the coastal receiving environment. The post flood samples showed that the background conditions quickly re-establish after the event.

Discussion and conclusion

Our synthesis of disparate data from monitoring programs and regulatory datasets, provides insights into the source and fate of TN in the Brisbane River that a single dataset could not provide. This study is the first time these data from different sources has been brought together to show the interrelations between flow condition, ambient water quality, point-source discharge and catchment sources of nutrients.

Upgrades to WWTPs greatly reduced ambient TN throughout the estuary in the mid-2000s but point-sources are still a significant influence for TN concentrations during low flows. In the mid-upper estuary, long residence time means that TN load is relatively stationary in the reach and removed at a rate of up to 2 % per day. In the lower estuary, dilution is the main driver of TN concentration with very little removal. During flood events, TN load is dominated by catchment sources, and transported directly to coastal receiving waters with no evidence of significant removal in the estuary. Overall, we show that little removal of TN occurs within the estuary, and that load and concentration during low flows is largely determined by point-source inputs.

Further investigation is required on the influence of moderately sized flow events. Those events that produce runoff and erosion in the catchment but may not completely flush the estuary. These flows were missing from our analysis and have the potential to deliver moderate loads of nutrient and sediment to the estuary without flushing to coastal waters.

Nutrient offsets based on erosion control in the upper catchment may have little influence on nutrient concentration and load in the estuary during low flows, which persist for the great majority of time. During high flows, erosion control-based offsets may reduce event nutrient loads, but the short residence time means that influence on the estuary is limited. To achieve water quality impacts at the same location and time as point-source discharges in the estuary, nutrient offsets would need to reduce concentration in the estuary during all flow conditions.

This work shows the value of integration and synthesis of multiple sources of data, which may be collected for disparate purposes, in addressing complex environmental issues and informing management actions.

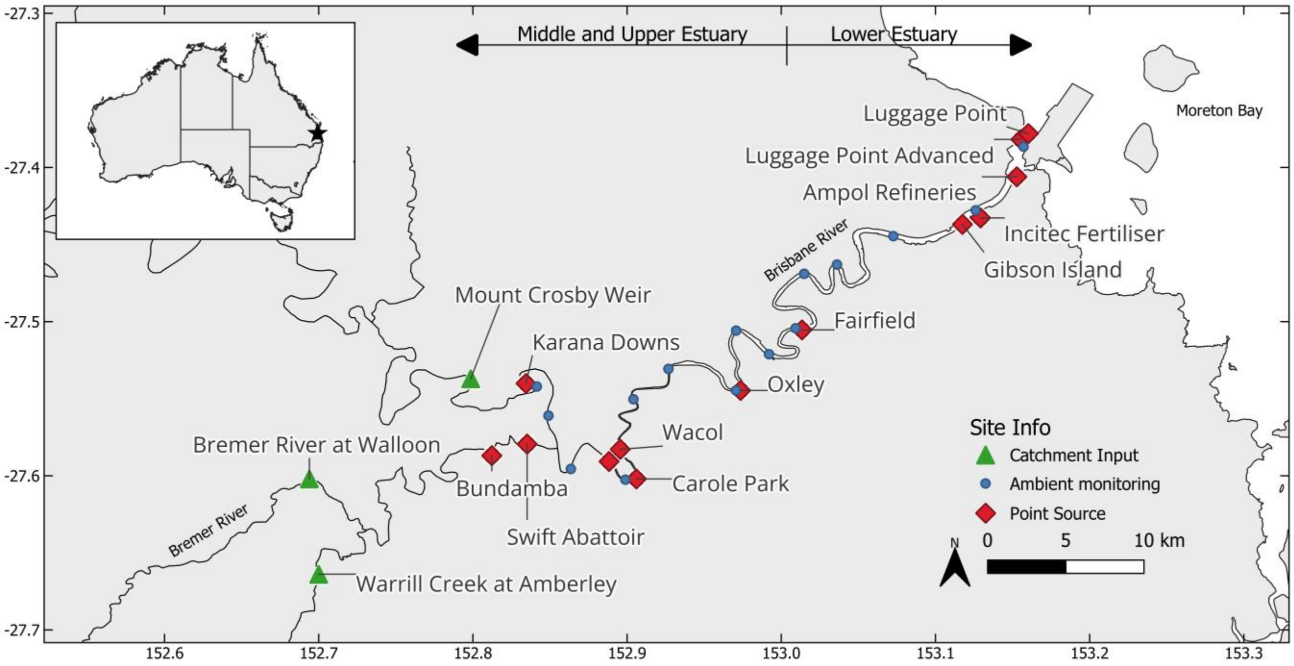

Figure 1. Map of Brisbane River estuary. Separation of lower estuary and mid/upper estuary is indicated at approximately 33 km upstream. Point sources of TN are shown as circles. Gauge stations where flow and nutrient concentrations were measured are shown as triangles. (Figure adapted from Newham et al. 2024).

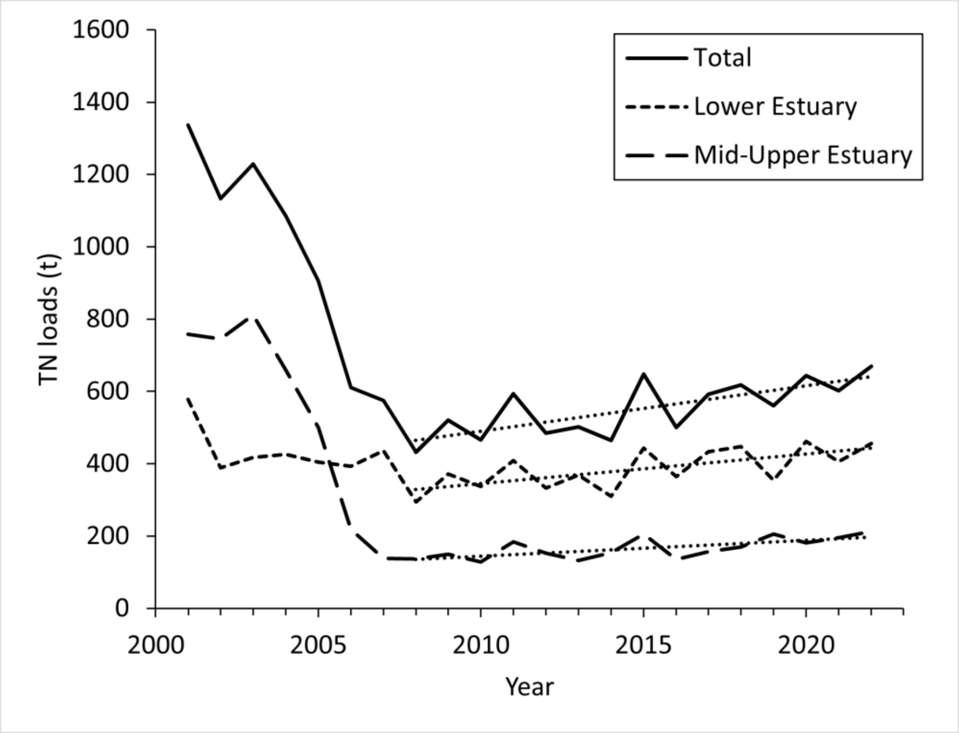

Figure 2: Annual point-source loads of total nitrogen to the lower, mid-upper, and total Brisbane River estuary. Linear trendlines for period 2008 to 2022 are shown. (Figure reproduced from Newham et al. 2024).

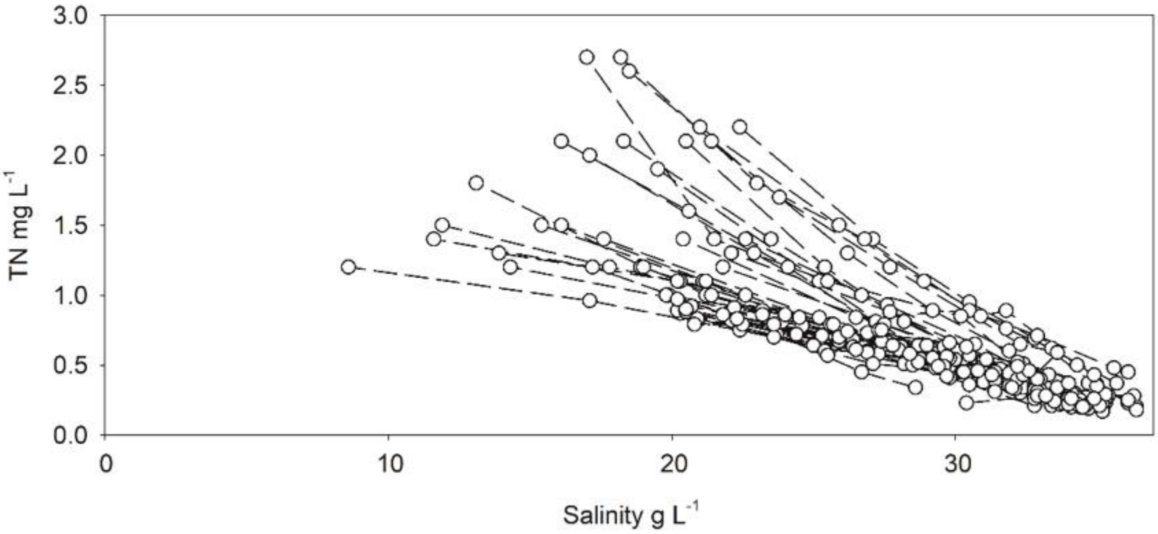

Figure 3: Lower estuary (0-33 km) concentration of total nitrogen (TN) versus salinity for low flows (flow <0.5% of estuary volume) from 2004-2008. Lines tie together samples collected on same day.

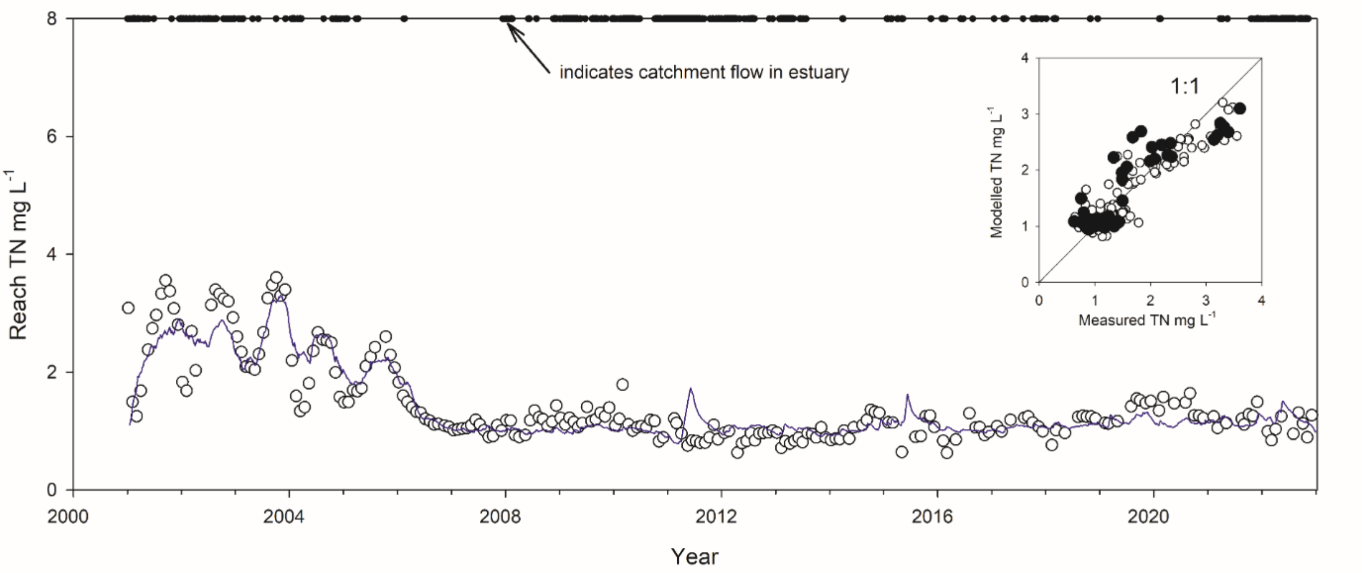

Figure 4: The observed volume-weighted average concentration of total nitrogen (TN) in the mid-upper estuary (33-81 km) (open circles) and the modelled concentration using point source loads (blue line). Goodness of fit was 0.86 between observed and modelled concentration during low flows. Significant deviations between measured and modelled concentration are associated with catchment inflows (indicated along top axis, flow >0.5% estuary volume). The inset figure compares the weighted average in-channel concentrations of TN and modelled TN concentrations for the low inflow periods (open circles) and high flow periods (black circles).

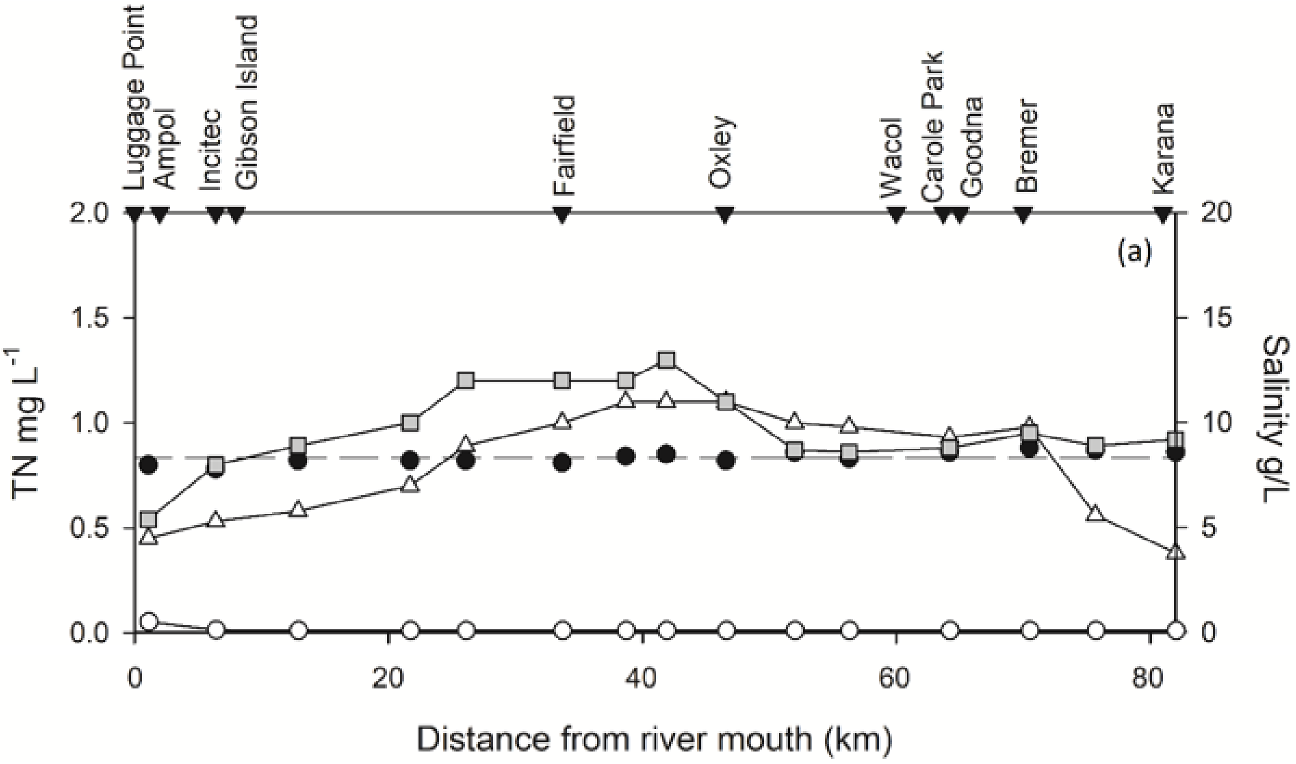

Figure 5: Total Nitrogen (TN) concentrations with distance from the Brisbane River mouth for EHMP sampling rounds before (February 10th; open triangles), during (March 8th; black circles), and after (April 4th; grey triangles) the February-March 2022 flood event. Dashed line is average concentration of during flood samples. Salinity at each sample point during the flood event are shown (white circles). (Figure adapted from Newham et al. 2024).

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